ACTIVE MAGNETIC FIELD BASED SENSING SYSTEM FOR IMPROVED DETECTION AND DISCRIMINATION OF SIDE IMPACT CRASHES

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ABSTRACT

Motivated by the complexity and variety of real-world side impacts, the Magnetic Side Impact (MSI) approach for side-impact crash detection and discrimination is presented. NHTSA has issued a rulemaking proposal that requires improved occupant protection in side impact crashes. It proposes 100% passenger car compliance to a more challenging standard in the near future. OEMs will likely require new sensing technologies and configurations to meet the proposed NHTSA standard.

This paper discusses a sensing technology for improved side-impact crash detection and discrimination. The MSI system induces a time-varying, fixed frequency magnetic field into the vehicle structure using a wire coil transceiver located in the vehicle door or frame. The induced field can also be sensed at other vehicle locations using a second wire coil receiver that detects changes in the magnetic field flowing through it. In normal operation, the transceiver (and receiver) signals are constant amplitude sinusoidal voltages at the transmitted frequency. During a crash, the magnetic path around the transceiver and between the transceiver and receiver is perturbed, and the resulting changes in the magnetic field are superimposed onto the MSI waveform. The received signal(s) are demodulated; leaving a signal whose content is proportional to crash severity and general impact location. The MSI system has shown to provide fast and reliable time to fire (TTF) signals in both laboratory and crash testing.

The MSI uses electromagnetic waves for communicating crash information, resulting in extremely fast detection and clear separation of deploy/non-deploy events. Placing a transceiver and receiver at opposite ends of the door allows wider spatial coverage. This paper describes the model and shows crash-sensing performance and system benefits based on crashes using a full vehicle Body-in-White platform.

MOTIVATION

During the years 2000 and 2001, side impact crashes accounted for approximately 37% of driver deaths in the U.S. While the rate of deaths per new registered vehicle (less than 3 years old) in the US from frontal impacts was reduced by 52% over the last 20 years, the rate for side impacts has only been reduced by 24%. Improvements in side impact safety have clearly lagged those for frontal impact safety. A major reason for the lack of progress in side protection is due to the small crush zone. Improved side impact safety can be achieved through improvements to structure, restraint/airbags, and sensing speed/accuracy. Better side airbags are always in development, but without improved sensing these restraints may not provide substantially better occupant protection.

Side impact sensing performance requirements have primarily been driven by regulatory tests (FMVSS 214 and EU 96/EC/27 Side Impact Regulations). Basic sensing requirements have focused on the need to rapidly distinguish severe regulatory developed crash modes from minor crash and abuse events so that restraint deployment will occur in sufficient time to protect occupants only when the crash could result in significant injury. In the past, regulatory agencies and consumers have relied upon OEMs to ensure robust side impact protection in real world conditions; however, newer crash modes have been proposed covering a broader range of real world impact scenarios [1,2] making the minimum sensing requirements more challenging.

Side impact sensing systems designed specifically to meet the existing regulatory crash modes may not perform optimally under a variety of real world crash scenarios [3]. National Highway Transportation and Safety Administration

(NHTSA) crash testing for side impact pole events showed that although several existing sensing systems deploy properly during a standard FMVSS201 pole impact, they do not deploy at all during an oblique pole impact [4]. In comparing these crashes, the lateral impact velocity is the same, only the incident angle is changed from 90 to 75 degrees and the impact location moved from a 50th percentile male to a 5th percentile female seating position (a separation of perhaps 15 cm or less). These test results imply that existing sensing systems may be inadequate under a variety of real world crash conditions.

Statistics

Statistics on side impact crashes are generally classified into two categories, car-to-car and car-to-fixed object. (i.e. pole, tree, stationary car, etc.)

Evaluation of the NHTSA National Accident Sampling System (NASS) database for car-to-car side impact crashes between 1998-2002 shows that the angular distribution of relative impact force direction (~ impact angle) has a mean of approximately 63 degrees with the majority of Maximum Abbreviated Injury Score (MAIS) 1-6 injuries falling within 30 and 90 degrees.

Side impact crashes into fixed, narrow objects (e.g. pole, tree) account for about 20% of all deaths and serious injuries in side crashes. The mean impact angle, or principle direction of force, for real world crashes of this type is about 60 degrees and the distribution of angles is quite wide ranging (majority range from 30 to 90 degrees). Current regulatory barrier and pole tests are run at a 90 deg. impact angle, which may provide a good evaluation of restraint performance for severe impacts, however, these test conditions are not the most challenging for evaluating sensor performance.

Regulatory Testing

NHTSA has issued a notice of proposed rulemaking [4]. The proposed rule suggests that a 75 degree pole impact for the 50th % male and a similar test for the 5th % female are appropriate test additions to the current FMVSS214 standard. The ideal sensing system will sense the crash for pole impacts occurring over a wide range of angles and impact locations along the door rather than being tailored to perform for regulatory crashes.

The Insurance Institute for Highway Safety (IIHS) has been performing side impact testing to address real world vehicle-to-vehicle compatibility. The IIHS impact sled is heavier, has a higher bumper area, and has approximately ½ the initial contact impact area compared with the NHTSA 214 barrier sled. This barrier reflects the growth in the light truck and sport utility vehicles (SUV) market in the U.S. (~37% of vehicle market share). In the years 2000-2001, 57% of driver deaths during side impact with another vehicle occurred when the striking vehicle was a pickup/SUV [5]. For impact with an SUV, the occupant of the struck vehicle is more likely to sustain severe head injuries due to the higher potential for direct head/upper body contact with the SUV hood. The high intrusion rate of the IIHS side impact test requires faster crash detection times than similar speed crashes with the FMVSS 214 barrier.

The European Union EU 96/EC/27 side impact barrier, compared with the FMVSS 214 barrier, is softer and has a larger initial impact area. The reduced stiffness and wider contact area of the EU barrier leads to significantly different signals for some sensors as the barrier itself absorbs and damps more of the initial impact energy. In this case, the transfer of energy into the impacted car may still cause severe deformation, but it may be more difficult to rapidly separate a more severe EU barrier crash from a less severe 214-barrier crash.

The challenge for next generation side impact sensing systems is to provide wide area coverage, fast response, and good response for severe crashes over a range of impact stiffness, area, location and angle while maintaining immunity to false deployment from abuse events.

BACKGROUND

The greatest threat to an occupant involved in a side impact crash is the penetration of the internal door structures or the impacting object into the head, thorax or hip of the occupant [6]. For this to occur, sufficient impact energy must be transferred into the impacted car to cause door displacement relative to the frame and door deformation. The function of any side impact crash sensor system is to quickly detect and discriminate the wide variety of potential crash events and deploy airbag restraints in sufficient time to protect the occupant. Typically, the time required to inflate the airbag can be between 10 and 20 milliseconds. For a regulatory high-speed impact, such as an IIHS, the required crash detection time can be less than or equal to 5 milliseconds. During this time, the penetration into the vehicle side structure may be as small as 5 centimeters. Such a relatively minor dent might also be expected for many non-threatening impacts (fender bender). So the ideal side impact sensing system should be capable of quickly detecting both deformation and deformation rate of the vehicle structures, which threaten the occupant directly and provide resistance between the occupant and the impacting object.

Accelerometer Sensors

The majority of current state of the art side impact sensing systems is composed of one or more lateral axis accelerometers mounted on each vehicle side. These systems evolved from frontal impact systems where a long crush zone and large structural mass help integrate and damp crash energy to the accelerometer; with less dependence on the impact point, area and direction of force. In frontal impacts, the distance between the impact object and the occupant is long and the accelerometer can be placed in a very benign location where it is relatively immune to shock and vibration induced by non-crash events (occupants, rough road and abuse).

However, for side impact crashes, the situation is very different. There is a short crush zone for side impact and the typical occupant compartment is composed of a variety of rigid (A, B, C pillar) and less rigid (door, glass) structures. The energy transfer paths for side impacts varies greatly depending on the crash location, impact angle, contact area and impact energy, making it extremely difficult to select the ideal location for a 1-D point sensor to quickly detect all real-world crash variations (poles, soft and hard barriers, impacting angles) and suppress all non-crash testing variations (abuse, rough road, minor crashes). Often, the only viable method to accomplish faster and reliable detection for the newly envisioned crash modes is to incorporate more accelerometers, which increases system processing complexity and cost.

Pressure Sensors

Several other technologies have been proposed to replace or augment the performance of accelerometers in an attempt to improve side impact crash detection and discrimination. A specific example is the use of a pressure sensor enclosed within a vehicle door cavity. Such a sensor provides a pressure pulse signal upon impact. This signal, combined with those from accelerometers may provide faster response for some crash modes, which are difficult to detect with accelerometers alone. However, for non-cavity applications (3rd row seat, or panel vans), or where the seal integrity of the cavity may be compromised (e.g. holes in the door, or interior trim or speakers removed), or when impact occurs on the cavity perimeter, a pressure sensor may have difficulty improving detection and discrimination [6].

MAGNETIC CRASH SENSING

The use of electromagnetic physics for crash sensing is an evolution that potentially provides enhancements in the speed of sensing and the wider distribution of response. During the general development of sensing methods in many applications, the sensing technology often evolves from mechanical sensing to electromagnetic field sensing. Field sensing, in general, often provides faster, more accurate, and more reliable sensing where the sensed phenomena can be tailored by sensor design rather than limited by mechanical mounting and mechanical interactions. For metal body cars, or bodies augmented with metal coatings, magnetic field sensing has the potential to provide rapid, wide region sensing of mechanical phenomena at a competitive cost. The MSI system, in its simplest form, consists of a device for creating a known magnetic field near the vehicle metal and a way to detect if this field is rapidly changing due to metal motion and deformation in a crash.

Electromagnetic Relations

The basic physical relations that define all electromagnetic phenomena are defined by Maxwell equations [7]. The primary equations needed to describe the MSI system function can be simply stated as:

Ampere's law: the magnetic field in space around an electric current is proportional to the electric current (which serves as its source).

Faraday's law: any change in the magnetic environment of a circuit (e.g. coil of wire, conductive sheet) will cause a voltage to be induced in the circuit.

Gauss's law for magnetism: The net magnetic flux out of any closed surface is zero such that all magnetic flux lines are closed loops.

Creating Magnetic Fields

Applying a current to a wire is a common method for creating a magnetic field (Ampere's law). By arranging the wire in a loop, the direction of the magnetic field along the loop axis can be controlled. The field magnitude is directly proportional to the product of the current in the wire and the number of turns in the loop. The current waveform signal applied to the coil will match the induced magnetic field waveform. Applying a discrete frequency sinusoidal current to a coil of wire generates a sinusoidal magnetic field at the same frequency along the coil axis.

Sensing Magnetic Fields

Faraday's law states that a voltage will be induced in a wire coil if the magnetic field enclosed by the coil changes in time:

$$V_{\text{ind}} = -N\dot{\Phi} \qquad (1)$$

Here V_{ind} is the induced voltage measured across the coil leads, *N* is the number of coil loops, and Φ is the magnetic flux that passes through the coil. Accordingly, a coil is also a very simple, but effective sensor for measuring time variant magnetic fields. The MSI uses a sinusoidal magnetic field which is inherently time variant providing the control system with an expected continuous waveform. Changes from the nominal magnitude and phase of this waveform provide information about changes in the vehicle metal.

Electromagnetic Fields in Conductors

In conductive materials such as steel, aluminium, and copper, an externally applied DC magnetic field will be equally distributed within the cross section of the material. However, as a sinusoidal field is applied at increasing frequency, Faraday's law predicts that induced electric voltage potentials will be produced in the conductor. These voltage potentials cause free charges in the metal to move, forming currents, commonly called eddy currents. These induced currents produce a secondary magnetic field, which opposes the original field according to Lenz's law [7]. These eddy currents extend into the conductor, with the magnetic field created by each deeper eddy current loop adding to the total opposing field. The result of this phenomenon is that the current density increases at the surface of the conductive material and decreases exponentially at greater depths. Skin depth (d) is defined for a conductor as the distance from its surface to the depth where the current density is 1/*e* times the surface current density:

$$d = (\pi f \mu \sigma)^{-1/2} \qquad (2)$$

where f=frequency (Hz), μ= magnetic permeability (H/m), σ=electrical conductivity (S/m), and ln(*e*)=1. For standard steel materials, in the frequency ranges that the MSI operates in, the skin depth is on the order of approximately 0.2 mm.

Magnetic permeability is a physical property that indicates how easily a material will temporarily magnetize in response to an applied magnetic field. For highly permeable materials, such as most steels, it is energetically favorable for the applied magnetic field to stay in the magnetic material. However, the eddy currents attempt to cancel this applied magnetic field. As the frequency of the applied magnetic field increases, the eddy currents constrain the field into an increasingly thinner layer at the surface of the conductive material, increasing the magnetic energy density of the system. Any electro mechanical system will find the state where there is a minimum total magnetic energy and, in this case, achieves this minimum by forcing portions of the magnetic field into the air near the surface of the conductor. For frequencies in the range from approximately 10kHz to 100kHz (MSI operation), it is energetically favorable for the magnetic flux to primarily reside in air more than in steel, but still be bound to a conducting surface. For frequencies above 100 kHz, an electromagnetic wave can develop that is no longer bound to a conducting surface. This is the frequency range where antennas operate.

Single Coil System (Transceiver)

A functional MSI system can consist of a single coil placed near one or more conducting surfaces that will move and/or deform relative to each other during a crash. This single coil functions as both the magnetic field generator (transmitter) and the sensor (receiver) of magnetic field perturbations and is referred to as a transceiver coil. Changes in the position and shape of metal in proximity to the coil cause detectable changes in the driving circuit impedance. Using Ohm's law, this change in impedance can be measured as a change in applied current for a constant peak voltage driven circuit. The change in impedance results from: 1) changes in coil inductive reactance as the coil inductively couples with nearby metal and 2) changes in coil resistance as the coil interacts with opposing eddy current induced fields in the nearby metal. Deformation and displacement of metal further away than a coil diameter will have less effect on the coil signal unless those motions couple to the nearby metal. The effective use of a transceiver, therefore relies upon proper coil placement relative to mechanical door structures, which cause motion and deformation in the regions near the coil. The transceiver coil is placed where it is certain to observe metal motion/deformation if the crash severity will warrant restraint deployment.

Two Coil Systems (Transmitter and Receiver)

A two-coil MSI system is a magnetic device, where one coil is used as a transmitter (or also a transceiver) of the magnetic field and another coil is used for receiving the field at another location. The signal from a receiver coil can add information about the crash.

The basic quantity that describes the transmission of the magnetic field from one coil to another is the complex *Reluctance* R_c. It is defined as;

$$\boldsymbol{R_c} = \frac{\boldsymbol{NI}}{\boldsymbol{\Phi}} \qquad (3)$$

where I is the transmit current. The reluctance is a measure of the magnetic "resistance" between two points. A crash event changes the reluctance between two points by altering the geometry of the metal and surrounding air so that the magnetic field paths are altered as a function of time. A system with a receiver coil detects changes in the field as the metal between it and the transceiver is disturbed, changing the amplitude and phase of the magnetic field reaching the receiver location. A two-coil system will have inherently broader area coverage of crash sensing than a single coil system. The magnetic field must travel through/around the vehicle components between the two coils, and the received signal will be dependant on mechanical changes due to a crash anywhere in this path. In addition, the use of a two-coil system provides the potential for a safing function.

We have introduced the concept of a 2-coil MSI system. Such a system has undergone extensive testing at Takata with successful crash discrimination results. However, it is much simpler to directly relate the crash dynamics to the signal response of a 1-coil transceiver. Additionally, a crash sensing system based on transceivers provides a near term solution to improve crash detection in response to new regulatory test modes. As such, the transceiver system will be the focus of the remainder of this paper.

Sensor Components (Transceiver)

The basic MSI transceiver system consists of the electronics, wiring harnesses, and transceiver coils needed to provide the crash detection coverage desired by the OEM. One transceiver coil for each door on a side could provide crash sensing

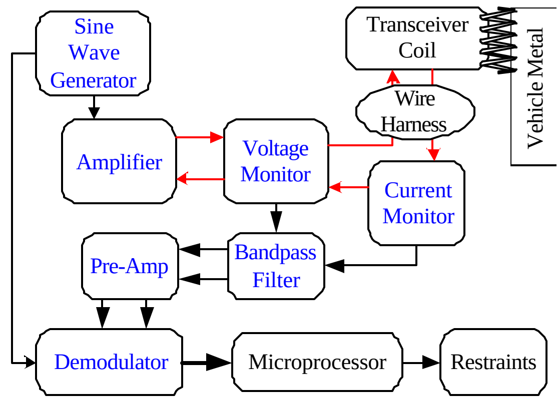

Figure 1. MSI block diagram.

for that side of the vehicle. The centralized electronics consist primarily of power conditioning, a circuit for generating the voltage (or current) supplied to the transceiver coil a circuit for monitoring the current and voltage supplied to the receiver coil and memory and processing capability to extract and process this magnetic signal through a crash discrimination algorithm. Figure 1 shows a block diagram of a basic MSI transceiver system; the red lines identify the excitation path, the black lines show the signal paths, and the blue text indicates functions that could be built into an application-specific integrated circuit (ASIC).

The sine wave generator creates a low distortion sinusoidal signal used to control the drive amplifier exciting the coil. Typically the sine wave will be operated at constant peak voltage and at a fixed frequency chosen from a range of about 20 kHz to 100 kHz. The generated sine wave will operate at frequencies above electric power and audible frequencies (50-60 Hz, 20 kHz) and below AM radio frequencies (>531 kHz), thereby producing an inaudible oscillation that is less likely to have mutual interferences with many existing electromagnetic systems. Because the MSI system uses a sinusoidal field, the field is constantly changing in time in a known way. Deviations from this expected constant-amplitude fixed-frequency sinusoid field are indicative of metal motion. This signal must be demodulated from the sinusoidal to extract the information about changes in the field. Standard techniques exist for removing or demodulating this signal by mixing the signal with the original sine wave generator signal. [8]. Before demodulation, each signal (voltage and current) undergoes band-pass filtering to remove noise and is then amplified to better optimise the dynamic resolution of the system. Demodulation allows measurement of changes in the magnitude and phase (relative to the sine generator) of the current and voltage signals. After demodulation, the signals are sent to a microprocessor where algorithms determine if the observed changes over time represent a crash of sufficient severity to deploy restraints.

The placement, orientation, and dimensions of a transceiver coil determine the primary metal motions and deformations that influence the sensed signal during the crash detection time (usually 0 to 30ms or less after initial crash contact). Figure 2 shows several candidate locations for the placement of a transceiver coil on a simplified door model. One location is inside the door (blue coil), near the occupant's hip, oriented to be most sensitive to inward motion of the outer door skin and reinforcement rail during a crash. Such an in-door transceiver coil would be primarily sensitive to door deformation along the axis of the coil in a region within about one diameter of the coil. Another location to place a transceiver coil is in the gap between the door and the frame, possibly on or near the pillar striker (red or green coil). This second transceiver location is sensitive to door deformation, but its response during the crash detection time is indicative of the whole door three-dimensional motion relative to the frame. While the majority of the signal in either of these arrangements is caused by metal motion in the region near the coil, coil locations can be chosen where the door structure and reinforcements will ensure that significant nearby metal displacement or deformation will occur within the required sensing time.

Figure 2. Candidate transceiver coil locations

Computer Aided Engineering (CAE) of the electromagnetic field and crash dynamics can be used to better understand the region of sensitivity and the response of the transceiver coil to deforming structures during a crash. As an example, Figure 3 show the computer predicted magnetic field shape within a simple steel box model, intended to approximate the aspect ratio of a vehicle door. A thin, flat coil whose size is approximately ½ the width and ¼ the length of the box is mounted over an access hole in the inside door panel (shown in the cross section as a thin purple line). The cross section shows that a symmetric field is created within the inner steel and air with intensity contours. The surface view shows the "bull's-eye" pattern of the magnetic field magnitude superimposed upon the inner door skin. This simple model provides a visualization of the sensing space of a " coil in the door" transceiver

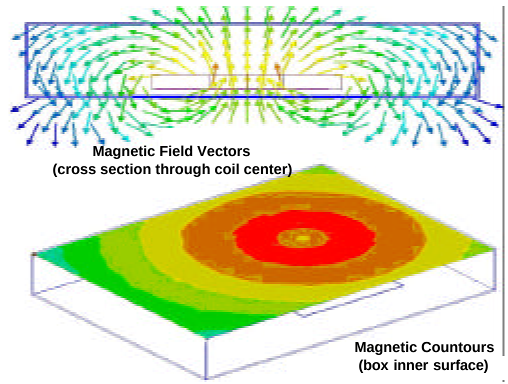

Figure 3. Magnetic CAE response for coil in door

Transceiver sensor response

To illustrate the sensing characteristics of the MSI transceiver for a basic in-door coil arrangement, a simple test was performed using 2 steel plates and a transceiver coil. The plates were 60 cm square sheets, 0.16 cm thick, composed of common 1006/1020-carbon steel. The transceiver coil used in these tests was a circular coil with a diameter of about 9.5 cm and an axial coil length of about 5.3 mm. The coil was wound with 88 turns of 22 gauge copper wire. The coil excitation frequency was 35 kHz and was driven at a constant peak voltage. The coil was placed on top of a fixed first plate and a second plate was moved incrementally towards the bottom plate. Figure 4 shows the laboratory set-up for the experiment.

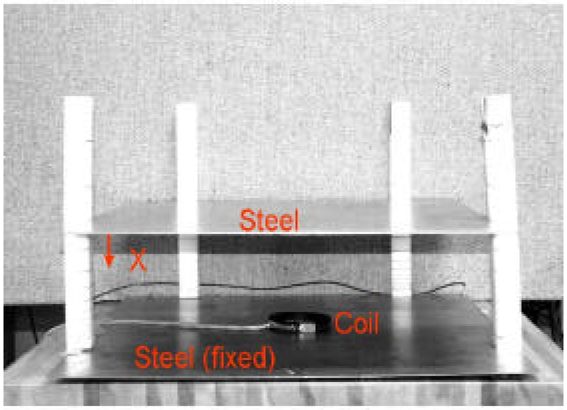

Figure 4. Transceiver response experiment.

Figure 5 shows a sketch of the experimental set-up and the transceiver sense circuit. The current in the sense circuit is allowed to vary while the peak voltage and excitation frequency are held constant. The change in current is a measure of the proximity of the top steel plate as it moves toward the coil.

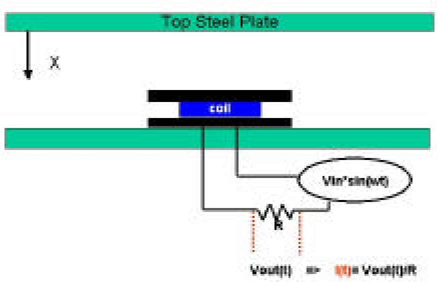

Figure 5. Transceiver experiment test circuit.

Figure 6 shows the static MSI transceiver current magnitude response as a function of the distance between the top of the coil plate towards the fixed bottom plate.

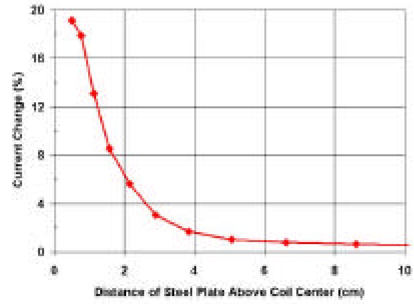

Figure 6. Magnitude response with gap change.

Note that there is also a phase shift in the measured current as the gap between the coil and the upper steel plate gap closes. This measurement is shown in Figure 7. Accordingly, the demodulated transceiver current and voltage provide both magnitude and phase information, which can be used to discriminate metal body displacement and deformation.

Figure 7. Phase response with gap change.

CRASH TESTING

The crash discrimination capability of the MSI transceiver has been demonstrated in a series of crash tests on a mid-size 4-door sedan Body-in-White (BIW) platform. While several transceiver designs performed well in crash discrimination, the performance response is perhaps best and most simply illustrated for a single coil mounted on the inner surface of the door back wall. In this location, the sensor response is determined primarily by the deformation and deformation rate of the exterior door skin and support beam relative to the coil.

This intrusion is directly related to the potential for occupant injury and *required time to fire* (RTTF).

Coil Selection

In a production application, the specific mount location for a transceiver coil on a given platform will be based on several criteria, including the vehicle geometry, door structural response to impact, the occupant types, seating locations and seat travel span. Also, the restraint RTTF would affect the sensor mounting location and size as illustrated in Figure 8.

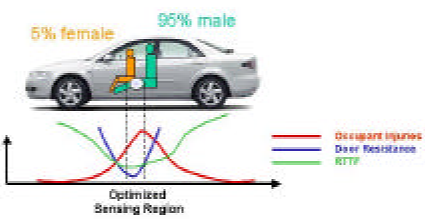

Figure 8. Occupant vulnerability and coil location.

The production location of a transceiver coil within the door must also consider the impact points of regulatory crash barriers that are derived from governmental statistics on side impact crashes and vehicle forms. Coil placement that is guided by these crashes does not limit the usefulness of the response in a variety of real world crashes, but rather places some extra sensing emphasis on crash locations where these agencies have determined that the occupant may be more vulnerable. These barrier and pole impact locations span the same region where various drivers may be located front to rear but provide a target height region where initial impact sensitivity may be most desirable. An example of how barrier location can influence coil location is shown in Figure 9.

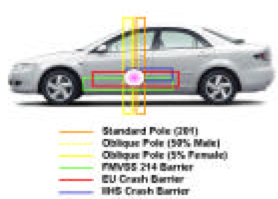

Figure 9. Barrier impact locations and coil location.

The selected coil location must also fit within the door mechanical and functional constraints (i.e. window, door locks, etc.). Ideally, the optical coil size, shape, location and mountings should be worked out using CAE tools in coordination with the platform designers.

Testing of the MSI system has shown that non-standard irregular shaped coils can be effectively used (i.e. elliptical, concave, oblong shapes, etc.). Additionally, PCB and flexible coils could be used when space is limited and conformance to existing structures is required.

The transceiver coil used in these BIW crash tests is a circular coil with a diameter of 17 cm and an axial length of 1.2 cm that was wound with 100 turns of 26-gauge wire. This coil was driven at a frequency of 33.5 kHz.

Test Matrix

In order to verify the crash discrimination performance of MSI transceivers, a series of crash tests were carried out, including a variety of barrier types and impact speeds. Each test conformed, as close as practical, to the regulatory published standards. Because the tests were carried out on Body-in-White vehicle without dummies, actual required TTFs cannot be determined. To estimate test repeatability, test 2 and test 5 were each executed twice (tests 4 & 6).

Table 1.
Crash Test Matrix

Test	Test Mode	Speed (kph)	Deploy
1	FMVSS 214	53	ON
2	FMVSS 214	19	OFF
3	FMVSS 214	32	ON
4	FMVSS 214	19	OFF
5	European Union	50	ON
6	European Union	50	ON
7	IIHS	50	ON
8	FMVSS 201 (Pole)	21	ON
9	Oblique Pole	23	ON

ANALYSIS

In each crash test, a high-speed data acquisition system (DAS) is triggered at impact (barrier contact = time zero) and the sensor current is measured as a voltage across a sense resistor at 16 bit resolution. The sensor current was processed using a 2^{nd} order band-pass filter with cut-off frequencies placed at +/- 3 kHz around the drive frequency. The data was then demodulated using the system clock and the complex signal magnitude passed through a 1 millisecond moving average and normalized to the pre-trigger to derive the response in Figure 10. In the Figure, the two black curves are the repeated non-deploy crashes and all other color curves are deploy condition crashes.

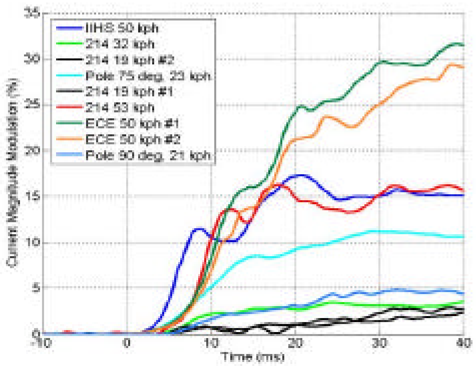

Figure 10. Coil in front door magnitude response.

This plot shows that the two OFF condition events can be separated from the remaining ON condition events. The majority of ON condition signals show a high rate of signal change within the first 3-7 milliseconds. Although the coil sensor was not optimised in terms of coil diameter and placement for these Body-in-White crash tests, the response trends are indicative of what would generally be expected from an optimised coil. Coil design, mechanical packaging and CAE can be combined to optimise the coil TTF and ON/OFF separation response for a given platform.

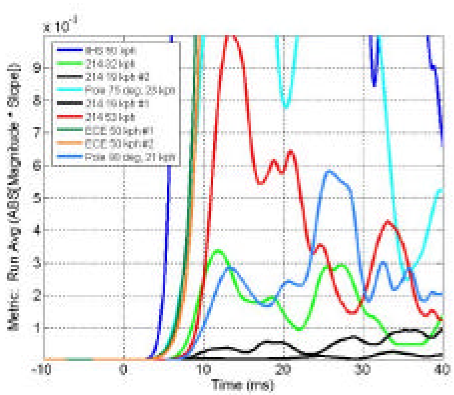

Figure 11. Simple crash metric (amplitude*rate).

In order to evaluate the crash discrimination potential that might be expected from a production intent electronic control unit, the 16 bit data was decimated to 12 bits and the data down-sampled to 3 kHz of bandwidth. The data was processed using a simple mathematical metric and provided the estimated TTF performance shown in Table 2. Figure 11 shows the result of one such simple metric. The magnitude data, shown in Figure 10, has been used to develop a metric that is the low pass filtered result of the absolute value of the product of the local average slope and the local average magnitude.

Using a second simple metric, estimated Time to Fires have been derived for the crash tests and are shown in the following table.

Table 2.
Crash test estimated time to fires

Test	Test Mode	TTF (ms)
1	FMVSS 214	5.3
2	FMVSS 214	OFF
3	FMVSS 214	6.2
4	FMVSS 214	OFF
5	European Union	6.5
6	European Union	7.0
7	IIHS	3.8
8	FMVSS 201 (Pole)	5.3
9	Oblique Pole	7.0

DISCUSSION/CONCLUSION

The crash detection and discrimination performance has been demonstrated for a single embodiment of an MSI transceiver sensor. The characteristics of this sensor can be controlled to optimally fit the sensing environment. This may be attractive to OEMs. Takata continues to develop an MSI system, initially based on transceivers, with the goal of improving system performance and coverage using a multi-coil system. Such a system has undergone extensive crash testing on several vehicle platforms with excellent results. However, in order to meet the near-term market need for improvements in side impact crash sensing, a first generation magnetic crash sensing system composed of one or two (rear door coverage) transceivers per vehicle side combined with a safing accelerometer mounted on the B-pillar is being developed by Takata.

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